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Analysis and Design of Keyboards for the AH-64D Helicopter

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Aircrew Health and Performance Division

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The trend towards digital cockpit designs has created the need to provide data entry keyboards in the cockpit. Using data representative of text entries used by pilots flying the AH-64 Apache helicopter, a quantitative model was developed of how long it would take to enter this kind of text with the current keyboard used by the pilots. The model was used to create an alternative optimized keyboard that arranges the layout of letters in a way that should allow (according to the model) much faster entry of the text. An experiment demonstrated an advantage for the optimized design over the original design of an approximate 31% improvement in data entry time.

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Introduction

Many military helicopters now include computers that process and display information about flight paths, engine status, weapon targeting, and geographic locations. Also useful is the ability for crewmembers to send and receive short text messages (STMs). A keyboard is provided for crewmembers to enter much of this information, but because of severe space constraints, the standard QWERTY keyboard is often not feasible. A standard keyboard would be of limited benefit anyhow, as possible positions of the keyboard in the cockpit and other crew member tasks prohibit the use of two hands for entering text. Discussions with pilots indicate that text entry in military helicopters is almost exclusively done by one-finger typing.

Figure 1 shows the pilot's cockpit of the AH-64D Apache attack helicopter. The keyboard in this cockpit is visible near the middle-left edge of the image. Figure 2a shows a schematic of the keyboard (the copilot uses a different keyboard); the letters of the keyboard are arranged alphabetically.

Francis and Rash (2003) described a software program called KeyboardTool that can create optimized keyboard designs for any specified text corpus. The program is derived from an earlier program called MFDTool that creates optimized multifunction displays (MFDs) (Francis, 1999, 2000, 2003; Francis and Rash, 2002). Data entry keyboards can be described as MFDs with a hierarchy of information that is only one level deep.

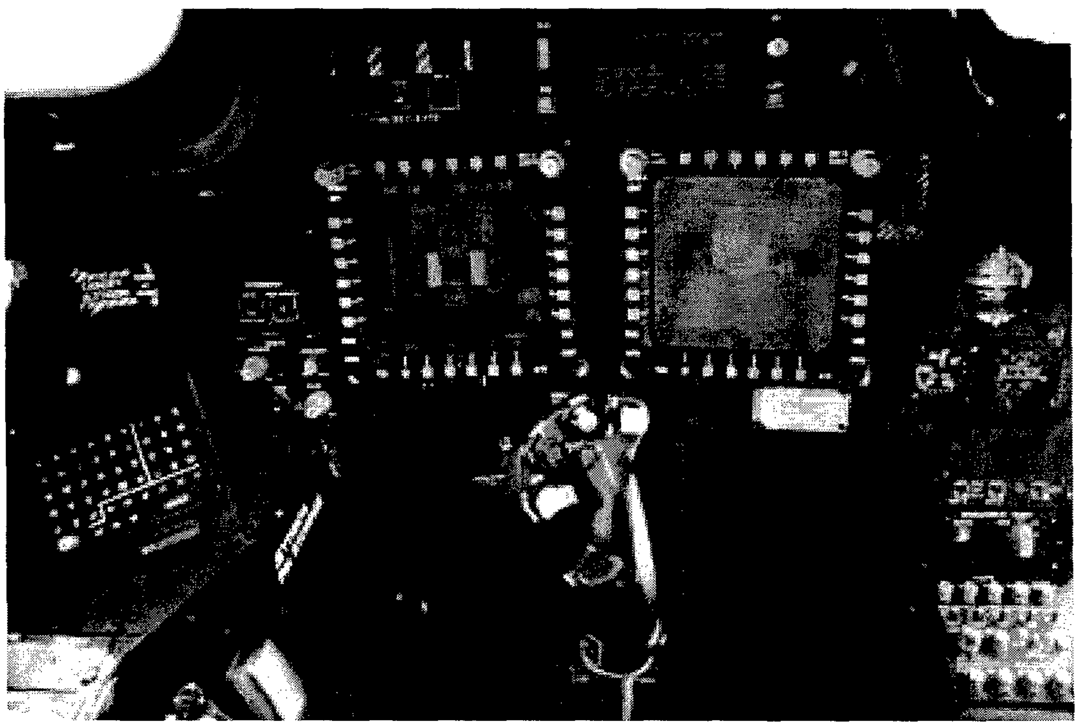


Figure 1. The pilot's cockpit of the AH-64D Apache attack helicopter. The keyboard is on the left hand side.

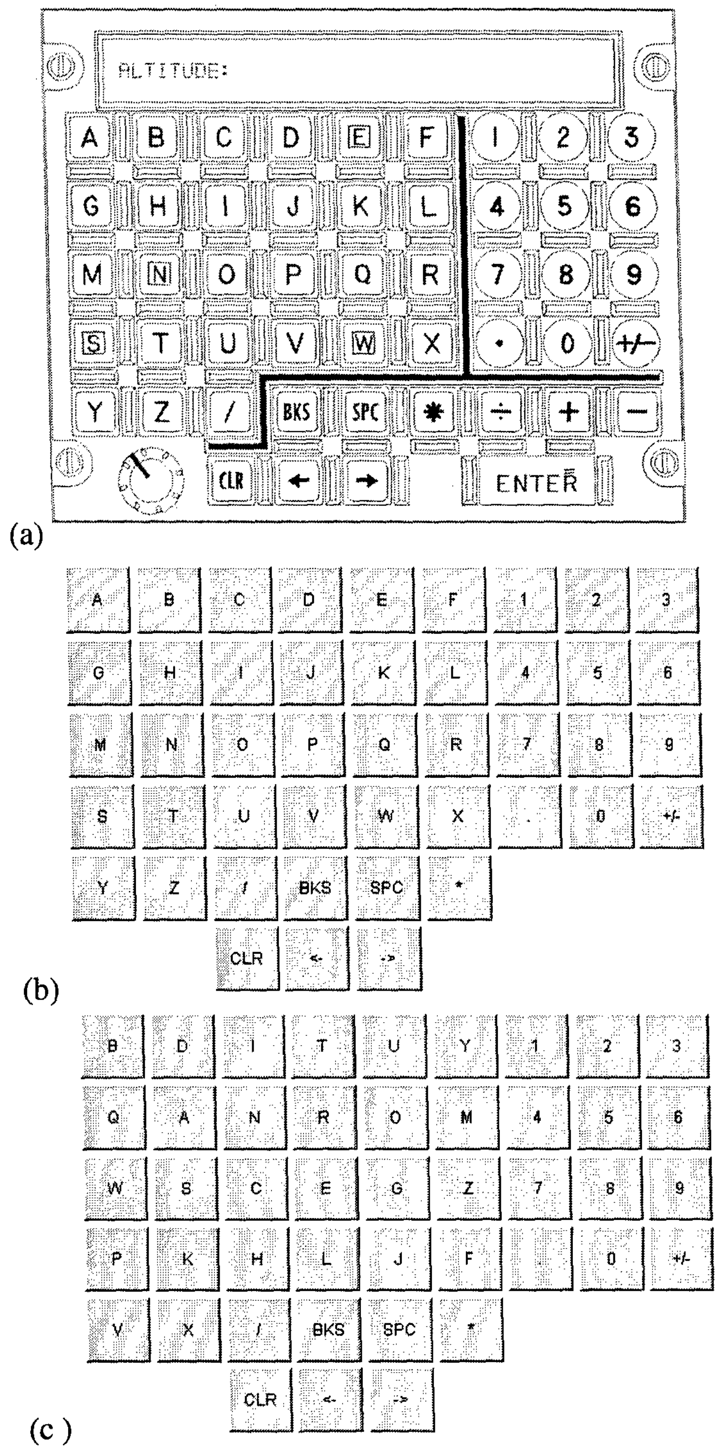


Figure 2. AH-64D keyboards. (a) A schematic of the keyboard currently used by the pilot of the AH-64D. (b) Simulation of the current AH-64D keyboard. (c) Optimized version of the AH-64D keyboard.

The current study was an investigation into whether optimized keyboards would offer any advantages over current keyboards. The pilot's keyboard of the AH-64D was used as a starting point for the investigation. The study involved four parts. First, a simulated keyboard was created in KeyboardTool. Second, a model of text entry time was developed to analyze text entry on the original keyboard. Third, the model of text entry time was used to develop an optimized keyboard that minimized predicted text entry time. Fourth, the original and optimized designs were tested empirically.

Simulated keyboards

The first step in the analysis was to create a simulated version of the pilot's AH-64D keyboard. The simulated keyboard was then used to provide a theoretical analysis of entry times, to identify an optimized layout of letters on keys, and for an empirical study of entry times. Figure 2a shows a schematic of the pilot's AH-64D keyboard, and Figure 2b shows the simulated version of the keyboard. Since only the alphabetical and numerical keys were planned to be used in the analytical and empirical parts study, other keys were not generally simulated. Some other keys were simulated if their absence would leave a notable gap in the keyboard design.

Theoretical analysis of original keyboard

The theoretical analysis was a prediction of how long it should take to enter specific text. The theory was based on Fitts' Law (Fitts, 1954). This law predicts how long it should take to move a certain distance (from one key to another) to reach a target of a given size. For a specific set of text and a given keyboard design, an estimate of the total entry time was found by adding up all of the predicted times needed to move from one key to another.

The predicted entry times were based on the assumption that an individual used a stylus or single finger to enter text. The predicted time was actually a prediction of the *minimum* entry time for a highly trained person making a single movement. Actual entry time on a keyboard may be much longer than predicted. At the same time, all of the predicted times could be easily scaled to be larger or smaller than what was given by the prediction. Thus, the important issue was the comparison was across keyboards and not the absolute predicted entry time.

After conversations with several pilots, a corpus of the kind of text that was likely to be entered by an AH-64D pilot was compiled. The Table lists this text. It included both short text messages (e.g., "LOUD AND CLEAR") and alphanumeric entries of coordinates and call numbers (e.g., "N2543.10"). The text messages are probably a good representation of the short messages that are sent by crew members during a flight. On the other hand, the coordinates and call numbers are simply examples of the *kind* of text that is entered. The actual numbers and letters probably vary tremendously across aircraft and missions. Differences across keyboards for alphabetical text entries are probably more significant than differences across keyboards for the numerical text entries, because the latter can vary more substantially than the former.

Figure 3 shows the predicted entry time for the text in Table 1 (with some exceptions as discussed below) for the original AH-64D keyboard design. Figure 3a shows the total entry time, which includes both alphabetical and numerical entries. Figure 3b shows the entry time for the alphabetical entries only. Figure 3c shows the entry time for the numerical entries only.

Table 1.
The kind of text entered by AH-64D pilots. The text was used to analyze text entry times on the keyboards.

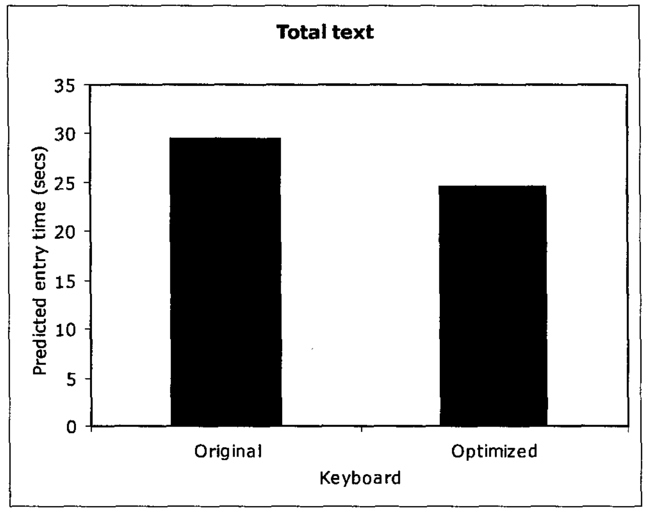
Alphabetical	Numerical
GO2	16R
GO TO	FJ3456
LC	7987
LOUD AND CLEAR	1200Z
RGR	32S
ROGER	MV1234
COMO CHK	1234
COMMUNICATIONS CHECK	N3214.50
BAQ	W13522.34
ENRT	18S
EN ROUTE	UH6789
	4321
	N2543.10

Creating optimal keyboards

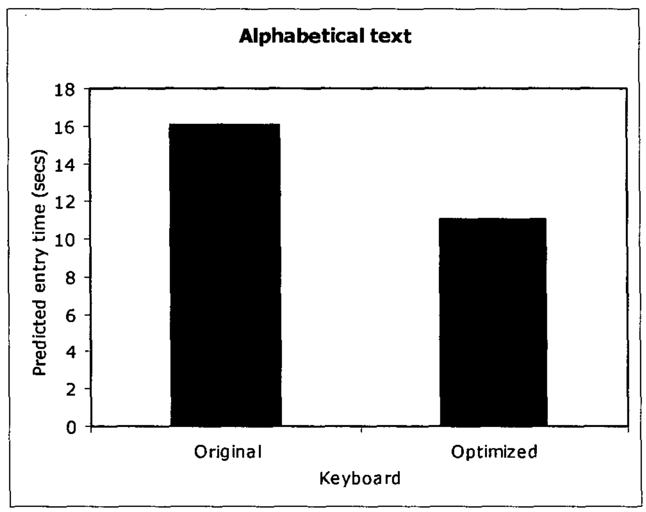
On the original AH-64D keyboard, the letters were arranged alphabetically, which may offer some benefits in terms of foreknowledge of where letters will be located. However, these keyboards were not designed to enter information as quickly as possible in the context of a helicopter cockpit. In an early study on these issues, Mavor *et al.* (1987) noted that the design of a keyboard impacted the ability of pilots to enter information quickly with minimal interference for other flight tasks.

For example, a commonly entered short text message was "RGR." To type this phrase on the original keyboard required the pilot to move a finger back and forth across the keyboard. The time to move back and forth across the keyboard may seem short, but it is time where the pilot must take a hand off the helicopter controls and possibly focus attention on the keyboard rather than on flying the aircraft. An alternative keyboard could conceivably reduce the text entry time and thereby be both easier to use and contribute to better overall flight performance and safety.

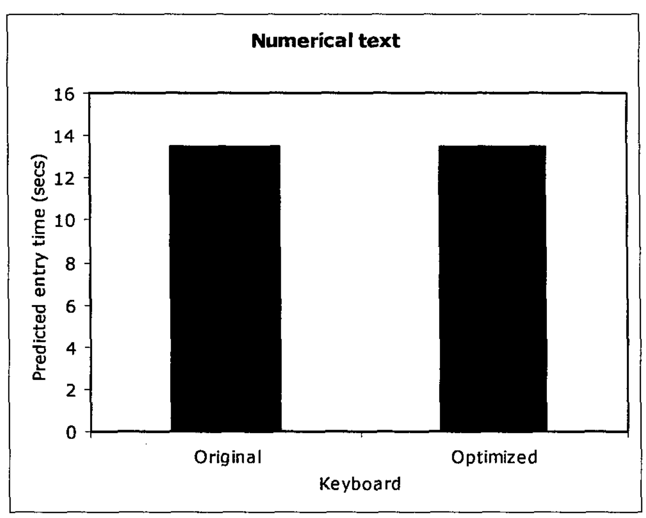
A computer program called KeyboardTool (Francis and Rash, 2003) can build an optimized keyboard. It requires four types of information. First, the physical arrangement and size of buttons must be specified. This was done with a graphical user interface in the KeyboardTool program (the same program made the simulated keyboards in Figure 2). The physical layout of the optimized keyboard was the same as the original keyboard. The creation of an optimized keyboard involved only modifying the layout of alphabet keys on the keyboard (the numerals, SPACE, and other keys kept their original locations). Second, the labels for the keys must be



(a)



(b)



(c)

Figure 3. Predicted entry time (seconds) for the original and optimized keyboard. (a) Total entry time for both alphabetical and numerical texts. (b) Entry time for the alphabetical text only. (c) Entry time for the numerical text only.

identified. This was just the alphabet letters (all upper case). Third, the time required to move between every pair of buttons must be given. KeyboardTool provided calculations of a variety of movement times; and for the optimizations here, the movement times were based on Fitts' law (Fitts, 1954). Fourth, a corpus of text must be provided. This was the alphabetical text given in the Table.

For the provided physical arrangement of the keys and labels, KeyboardTool found the assignment of letters to keys that minimized the predicted time required to enter the given text. Figure 2c shows the optimal keyboard that minimized the predicted entry time of the alphabetical text in the Table.

The effect of the optimization can be easily identified. Consider entry of the short text message “RGR,” which required substantial movement across the original keyboard. In the optimized keyboard, the letters were right next to each other. A similar arrangement was present for other short text messages.

Optimization across the entire text corpus does not mean that every word can be entered quickly. For example, on the optimized keyboard, entry of the word “COMMUNICATION” required substantial movement across the keyboard. The optimization works to find the placement of letters to keys to minimize the overall entry time across all words and phrases. Thus, the letter assignments may lead to a situation where a relatively rarely used word may be entered slowly so that a more frequently used word can be entered quickly. The possible optimizations also depend on the physical properties of the keyboard. Some physical layouts of keys may support better optimization than other physical layouts.

Figure 3 summarizes the effect of the optimization by showing the sum of the predicted entry times for the items in the Table (with a few exceptions as discussed below). Figure 3a shows the total predicted entry time, which includes both alphabetical and numerical entries. Figure 3b shows the entry time for the alphabetical entries. Figure 3c shows the entry time for the numerical entries.

The predicted entry time for the optimized keyboard design was shorter than for the original keyboard design. Across the total text, the optimized keyboard reduced text entry time by 17%, relative to the original keyboard. Most of this reduction was driven by the alphabetical text. Considering only the alphabetical text, the optimized design was predicted to reduce text entry time by 31%, relative to the original design. There was no advantage of the optimized keyboard for the numerical text (which was expected because the keyboard was not optimized for this text and the number key pad was kept unchanged across the designs).

Empirical analysis

The empirical test of the keyboards involved having students in the Purdue University subject pool enter text on the simulated keyboards. A keyboard was presented on a touch screen monitor and the participant used a stylus (the eraser end of a pencil) to tap on the virtual keys of the keyboard.

Figure 4 shows how the experimental window appeared on one trial for one of the keyboards. The text at the upper left was to be entered on this trial. After entering the text, the participant was to click on the "Submit" button to finish the trial. The computer then verified that the participant entered the text correctly and provided feedback. If the text was correct, the next trial was started with the to-be-entered text changing. If the text was incorrect, the participant was told that the trial would be repeated later in the experiment, and then the next trial was started. Entry errors were rare. Across the 31 experimental trials, participants averaged 4.3 and 4.9 entry errors for the original and optimized keyboards, respectively.

On each trial, entry time was measured as the time between the first letter key press and the last letter key press of the to-be-entered text. The participant was allowed as much time as necessary to read the text and study the keyboard before starting to enter any text. The total entry time for the participant was then the sum of entry times across trials.

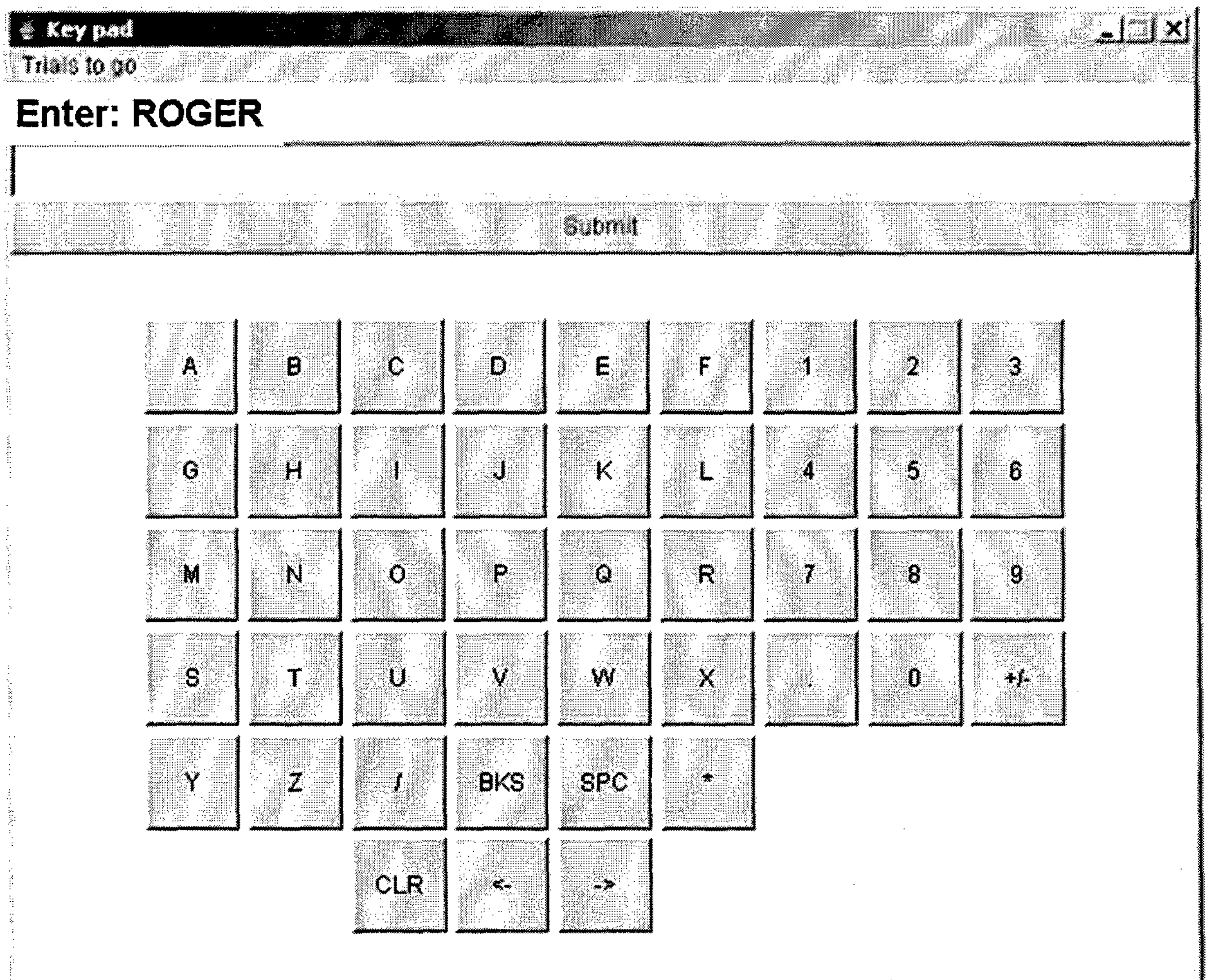


Figure 4. The experiment window.

Each participant worked with only one keyboard. Each experimental session began with 13 practice trials. These trials were ordered alphabetical and numerical trigrams (e.g., ABC, DEF, 0.1, 456). The practice trials gave participants an opportunity to familiarize themselves with using the stylus and touch screen monitor. The practice trials also insured that the participant found each key on the key and board. Two groups of 15 participants were randomly assigned to each keyboard.

An analysis of the data quickly identified two outliers among the text entry times. The average times to enter the STMs "LOUD AND CLEAR" and "COMMUNICATIONS CHECK" took between 9 and 17 seconds. The next longest average entry time was slightly over 6 seconds ("EN ROUTE" on the original keyboard). Coupled with observations of the participants during the experiment, the data pattern suggested that the exceptionally long entry times for the outlier texts was due to participants rereading the to-be-entered-text after entering parts of the text. This back and forth behavior increased the text entry time substantially in a way that would be independent of the keyboard design. Indeed, the average entry time for the outlier texts was nearly identical across the keyboards (13.1 seconds for the original keyboard and 13.2 seconds for the optimized keyboard). Thus it seems likely that the participants found these outlier texts to be particularly difficult to enter because their length taxed the limits of short-term memory. As a result, the data for the outlier text were removed from the main analysis. (Likewise, the predicted entry times in Figure 3 do not include the entry of the outlier texts.)

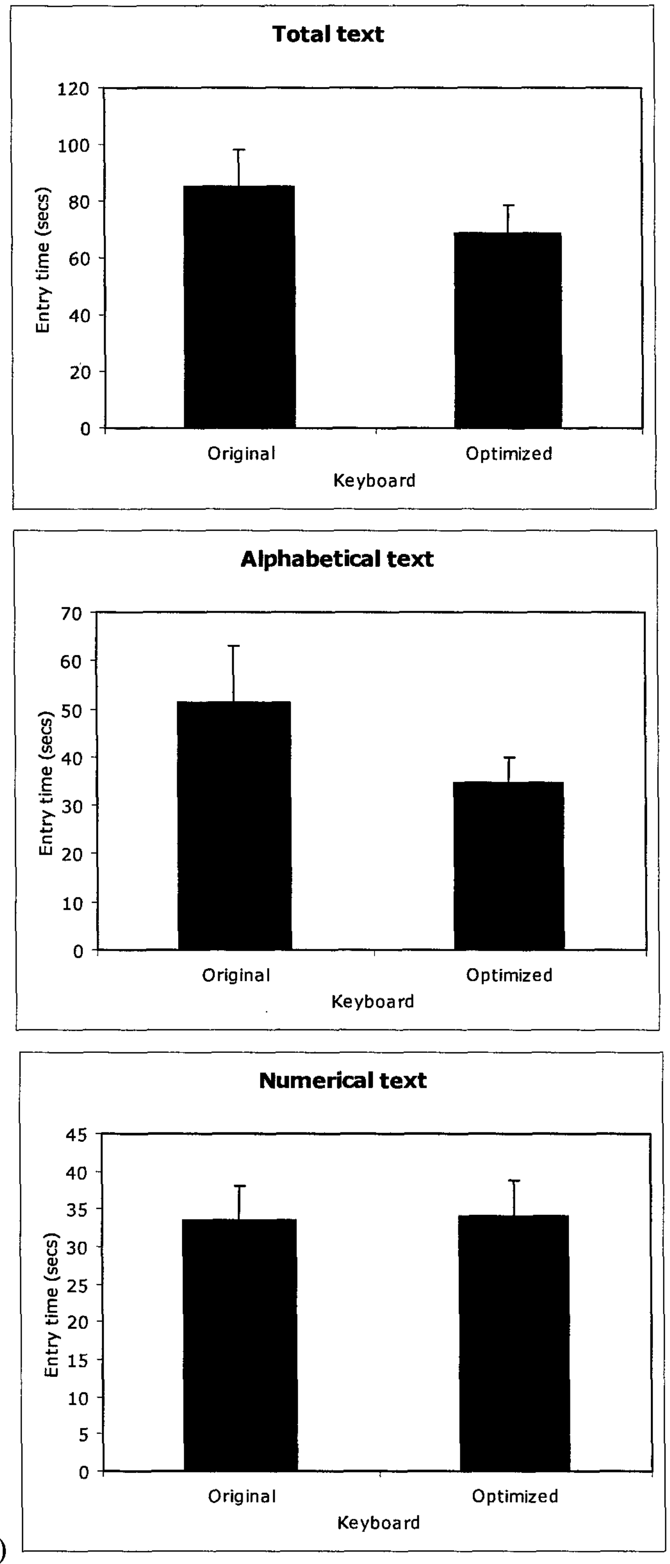
Figure 5a shows the total entry times (combining both the alphabetical and numerical entries). The difference between the original and optimized keyboards was statistically significant ($t=2.12$, $p<0.04$). Similar to the predicted effect, text was entered 19% faster on the optimized keyboard, relative to the original keyboard.

A similar pattern appears in Figure 5b for the alphabetical entries alone. The difference between the original and optimized keyboards was statistically significant ($t=2.74$, $p<0.01$). The effect of the optimization was close to what was predicted; text was entered 33% faster on the optimized keyboard, relative to the original keyboard.

The pattern was quite different when only the numerical entries were considered (Figure 5c). Text entry of the numerical items did not differ ($t= -0.17$, $p<0.86$). The lack of a difference was predicted by the model.

Learning effects

One possible objection to implementing specialized and optimized keyboards is that they may be difficult to learn. This objection is partially alleviated in the current situation by noticing that both the original and optimized keyboards are nonstandard and require some learning. At the same time, one might expect that the original keyboard with its alphabetical arrangement of keys would be easier to learn than the optimized arrangement because the former introduces a clear cognitive strategy for knowing where to find the needed keys. In contrast, the optimized keyboard has no clear organizational structure.



(a)

(b)

(c)

Figure 5. Mean entry times for the original and optimized keyboards. The error bars define the 95% confidence intervals around the mean. (a) Total entry time for both alphabetical and numerical test. (b) Entry time for the alphabetical text only. (c) Entry time for the numerical text only.

To explore this issue, the average key press time for each participant on each trial of the experiment was calculated. This calculation compensates for the fact that words with more characters must take longer to enter, if only because they have more key presses. Figure 6 plots the averaged key press time across participants for the experimental trials of the experiment. Learning effects should appear as reductions in key press time over trials.

Participants using the original keyboard design showed virtually no learning (the difference between the first and last experimental trials was around 10 milliseconds). In contrast, participants using the optimized keyboard design demonstrated a clear learning effect (the difference between the first and last experimental trials was around 100 milliseconds). Indeed, the learning curve for the experimental trials does not seem to have bottomed out, so still further reductions in entry time may be possible.

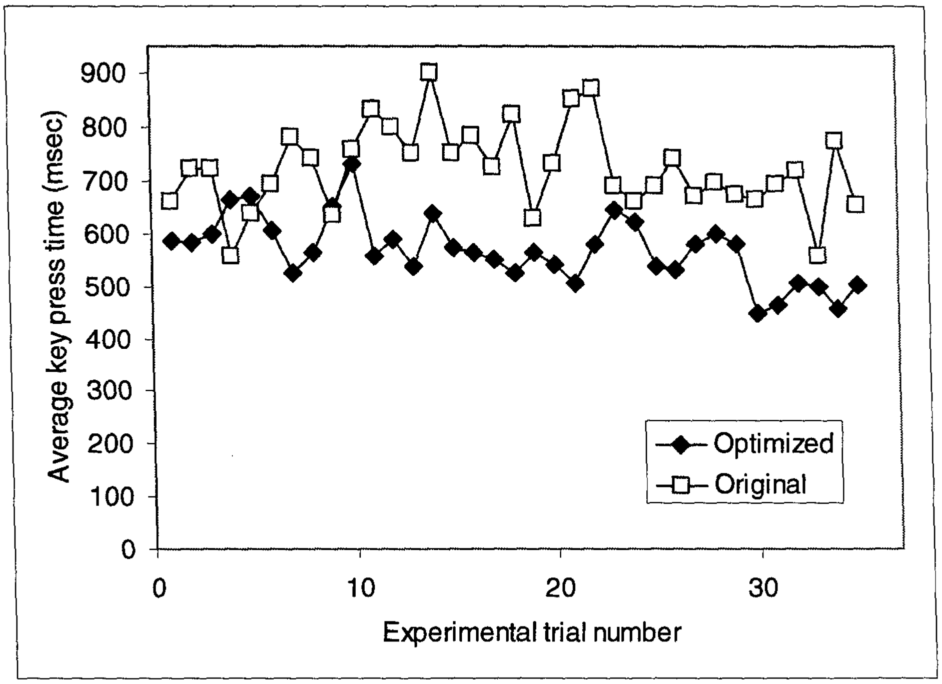


Figure 6. Learning effects during the experiment. Although average key press time decreases for participants using the optimized keyboard, there is virtually no change in key press time for participants using the original keyboard.

Conclusions

The main finding of this study was that the optimized keyboard promoted a 33% reduction in alphabetical text entry time, relative to the original AH-64D pilot's keyboard. This reduction was very close to the 31% improvement predicted by the model.

An important implication of this analysis is that it seems the cognitive organization of the original (alphabetically arranged) keyboard does not aid text entry as much as minimization of movement time. Further work is needed to explore whether this result holds generally or is specific to this particular keyboard and text corpus.

Similarly, the optimized keyboard promoted a stronger learning effect than the original keyboard. All of the participants in the empirical study were novices with the keyboards. One might have expected that the alphabetically arranged keyboard would promote faster learning, but instead evidence of learning was only found for the optimized keyboard.

Overall, the results of this study suggest that optimization of keyboards is both feasible and practical for military helicopters. More generally, any situation that requires a nonstandard keyboard could be optimized to allow quick entry of specific text. Optimized keyboards should become increasing useful as the military increases its digitization of equipment. The techniques and tools described in this report allow optimized keyboards to be quickly created and analyzed.

References

Fitts, P. M. 1954. The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology. 47, 381-391.

Francis, G. 1999. A software tool for the design of multifunction displays. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 99-20.

Francis, G. 2000. Designing multifunction displays: An optimization approach. International Journal of Cognitive Ergonomics. 4, 107-124.

Francis, G. 2003. MFDTool: A software program for designing optimal multifunction displays. Behavior, Research Methods, Instruments and Computers. 35, 236-243.

Francis, G., and Rash, C. E. 2002. MFDTool (Version 1.3): A software tool for optimizing hierarchical information on multifunction displays. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2002-22.

Francis, G., and Rash, C. E. 2003. Optimization of keyboard design for specialized text entry, Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting October 10-17, 2003 Denver, Colorado.

Mavor, A. S., Gal, C. A., Sawyer, C. R., and Christ, K. A. 1987. A comparison of keyboard designs for cockpit applications. Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory. Technical memorandum 24-878.